SESSION ON TROPOSPHERIC PROPAGATION BEYOND THE HORIZON—I

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GUGLIELMO MARCONI AND COMMUNICATION BEYOND THE HORIZON: A SHORT HISTORICAL NOTE

By G. A. ISTED.

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SUMMARY

The paper describes experiments, carried out between 1928 and 1936 by Guglielmo Marconi, which demonstrated that transmission beyond the horizon by means of microwaves was practicable. Furthermore the influence of tropospheric mechanisms on radio-wave propagation was recognized by him at the time.

In 1896, encouraged by Sir William Preece of the British Post Office, Guglielmo Marconi gave one of the first spectacular demonstrations of communication by means of radio waves. The frequency he used was of the order of 1 000 Mc/s. It is interesting that after over 30 years of investigation, during which period he worked successively on low, medium and high frequencies, he finally returned to his original band of frequencies in the years 1928–36.

It is also interesting to consider how different things might have been had Marconi not deviated from his original investigation of microwaves. We might by now, for example, have fully exploited the possibilities of microwave tropospheric scatter mechanisms. We might even now have been turning our attention to longer waves, where rumour would have it that communication could be established over still greater distances with less power than that used on microwaves, and we might now have been theorizing on the existence of the ionosphere. That might possibly have been the more logical evolution of the art of radiocommunication. It was, however, ordained otherwise, and we are now back, in many respects, to the point at which Marconi began his work.

It cannot be said that Marconi was ever an able recorder of his own technical achievements, and it has been left mainly to others who have had intimate knowledge of his work to place them on record. His work after 1928 was no exception, and it is the pleasant task of the author, who had the privilege of being one of his personal assistants at that time, to link the experiments which Marconi carried out from that year onwards with those being carried out at the present time.

In 1928 the Presidency of the Italian Royal Academy was conferred upon Marconi. This made it necessary for him to transfer his research activities and staff from England to Italy, although his work continued to be sponsored by British interests.

It is, of course, well known now that the troposphere profoundly affects the propagation of radio waves, particularly those with frequencies within the v.h.f. and u.h.f. bands and beyond. The first direct reference to the influence of the troposphere on radio-wave propagation was, however, made by Marconi. This reference was made in respect of experiments, using frequencies just above 30 Mc/s, which were requested by the Italian Government. These experiments, now briefly described, were carried out between Sardinia (Golfo Aranci) and the Italian mainland (Fiumicino).

Arrays of uniform aerials, each of which probably had a gain of about 16 dB, had been erected at both the transmitting and receiving sites, which were virtually at sea level. Transmitters, capable of being modulated by a single speech channel, delivered about 1 kW of power to the aerial. Thus the system achieved an effective radiated power of the order of 40 kW. The geometrical optical range given by the combined aerial heights was not more than 34 km and the distance was 270 km—some eight times the optical range.

The experiments showed quite clearly, by beam-swinging tests, that the angle of arrival of the signal was tangential to the horizon. Meteorological conditions, whilst never causing complete failure of signals, did cause a day-to-day and seasonal modification to the mean signal level. It was noted particularly that the signal level was some 20 dB less in winter than summer.

It was this experimental evidence which prompted Marconi[1] in his address to the Italian Society for the Progress of Sciences in 1930 to say:

> From measurements effected recently it would seem that along the route between Sardinia and the Italian mainland this wave is refracted and contained within a space lying between the surface of the earth and a layer situated somewhat lower than the Heaviside layer.

This is a fair description of the troposphere.

From the author's personal knowledge the fading characteristics on this test route were similar to those which we now observe on authentic tropospheric scatter circuits.

We must, of course, bear in mind that during these 30 Mc/s experiments sporadic-E ionization could have been present. It is also recorded that round-the-world echoes were observed which indicated the probability also of F_2-layer propagation; both these factors may possibly have influenced the results. Nevertheless, the continuous presence of the signal at all times makes it certain that tropospheric mechanisms must have been the dominant influence.

It was at the conclusion of these tests that Marconi turned his attention again to the investigation of the behaviour of microwaves. This time he was not alone in this field. Very early in the 1930's Uda[2] in Japan succeeded in communicating between Sendai and Otakamori, a distance of 30 km, on frequencies of the order of 600 Mc/s; Pistor[3] in Germany had made valuable contributions to the microwave art; Clavier and Gallant[4] established a 2-way communication link across the English Channel between St. Inglevert and Lympne on a frequency of the order of 1 500 Mc/s. Marconi himself very soon succeeded in demonstrating communication over distances of the order of 35 km on 600 Mc/s so convincingly that the Vatican authorities requested him to provide a similar equipment for communication between the Vatican and the summer residence of His Holiness the Pope at Castel Gandolfo. This installation, the first microwave telephone in the world, was put into regular service[5] in February, 1933. Marconi, however, had no real interest in these short-distance line-of-sight transmissions. His ambition was to break down the barriers which dared to impose limitations on the propagation of the radio waves he had made his life's study. With this in his mind he set himself the task of removing the barriers which, at that time, seemed destined for the first time to prevent him from communicating to distances beyond the horizon.

All workers in the microwave field in the early 1930's used

Mr. Isted is with Marconi's Wireless Telegraph Co., Ltd.

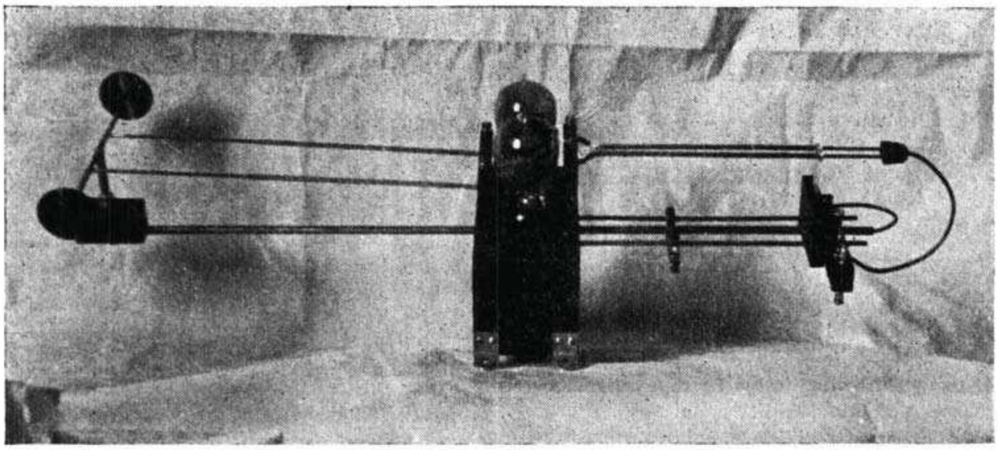


Fig. 1.—An early type of 600 Mc/s oscillator unit, using one pair of push-pull valves, connected in the Barkhausen–Kurz manner. The dipole is capacitance-loaded by circular end discs.

the humblest of apparatus. This fact explains the absence of the precise measurements to which we have become accustomed in the past decade or so. There were literally no radio-frequency devices available for the measurement of power, signal intensity, attenuation or indeed frequency itself. A brief description of the apparatus used by Marconi may therefore serve to demonstrate the difficulties under which he, and indeed other contemporary workers, carried out their pioneering work. It may also serve to enhance their early technical achievements.

The backbone of the electronic apparatus was, without doubt, the so-called electron oscillator.

Barkhausen and Kurz discovered in 1919 that, when they applied a negative potential to the anode of a triode valve and a high positive potential to the grid, very-high-frequency oscillations were set up; whether this was discovered by accident or design is not recorded. It was further found that the frequency generated in this manner, usually higher than 300 Mc/s, was largely dependent upon the applied potentials. Gill and Morrell, in 1922, showed how the Barkhausen–Kurz electron oscillator could be coupled to an oscillatory circuit.

Not every valve would produce the Barkhausen–Kurz continuous-wave oscillations, and when one was found which did, its life often terminated after a few minutes' operation, usually owing to the fact that the grid had melted.

One of the first requirements at this stage was a reliable valve. Marconi developed one during his first year's work which had a life of about 40 hours, and a power output of the order of 5 watts at a frequency of 600 Mc/s. A transmitting unit was developed consisting of two valves operating in push-pull with associated tuning lecher wires in the grid, anode and filament circuits; the dipole aerial was directly coupled to the grid circuit (see Fig. 1). Four of these units—eight valves in all—were used in parallel, all being kept in phase by an interlinking lecher-wire system; a formidable arrangement even by modern standards!

All four dipoles of this arrangement were situated in a broadside manner at the focus of a five-unit fishbone parabolic reflector. A conservative estimate of the effective radiated power of this particular arrangement is 4 kW.

Frequency modulation of the transmitter was obtained by the simple expedient of modulating the anode negative potential.

The receiver consisted of a pair of push-pull valves connected in the Barkhausen–Kurz manner and used in conjunction with a paraboloid aerial. A more portable version of this receiver, incorporating a fishbone parabolic reflector and dipole aerial, is shown in Fig. 2. The radio-frequency 'detector' was followed by a 2-stage audio-frequency amplifier—only four valves in all.

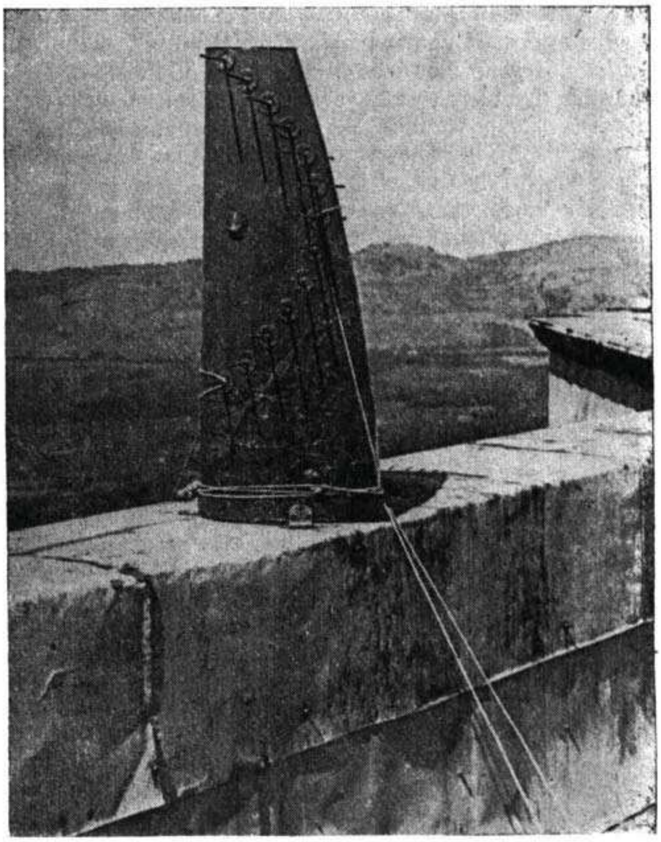


Fig. 2.—The portable 600 Mc/s receiver, incorporating a fishbone parabolic aerial, used in many of Marconi's experiments.

The secret of the success of this remarkable little receiver undoubtedly lay in the fact that, by patient and cunning manipulation of the grid and anode potentials, and the grid, anode, and filament tuning lecher wires, the receiver could be coaxed to the state where it just failed to oscillate on the required frequency; this state was superbly sensitive, as users of orthodox regenerative receivers will recall with some nostalgia.

It was with this apparatus, crude by modern standards, that Marconi set out in 1932 supremely confident that he would yet again confound the physicists and mathematicians of the day who were of the opinion that communication beyond the horizon was an impossibility by means of microwaves, or as they were then called, quasi-optical waves.

Marconi was particularly fortunate in having at his disposal the steam yacht *Elettra*, now alas, through the vicissitudes of war, lying at the bottom of the Adriatic. With this vessel he was able to study the behaviour of radio waves from their source up to distances at which signals were no longer audible.

The first experiments[6] were carried out with the transmitter installed on the roof of the Hotel Miramare at Santa Margherita, on the Italian Riviera; the receiver was located in the stern of the *Elettra* (see Fig. 3). This arrangement gave an optical range of about 27 km.

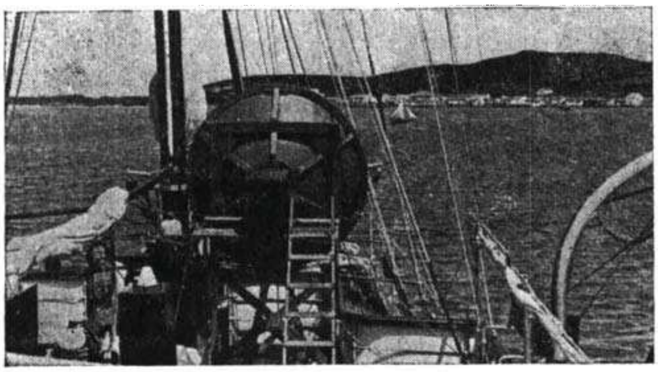


Fig. 3.—The 600 Mc/s receiver, with large paraboloid aerial mounted at the aft end of the *Elettra*'s boat deck, used for long-distance experiments.

Observations made while the *Elettra* steamed away from the transmitter showed repeatedly that signals could be received up to about three or four times the optical range. The behaviour of the signal repeated from one day to the next; the salient features being that up to the horizon fading was shallow and slow, but beyond the horizon fading became deep and fairly rapid.

Tests were carried out a month or two later from Rocca di Papa (Rome), from a height of 700 m, with the transmitting aerial array directed across the sea towards Sardinia. The receiver remained in the same position at the stern of the *Elettra*. The optical range under these new conditions was about 90 km.

Repeated tests again showed that microwaves could be reliably propagated to distances exceeding the optical range by two to three times. The behaviour of the signals conformed closely to those received from the lower transmitting terminal at Santa Margherita. During these experiments signals were received up to distances of 240 km. Continuing this series of experiments Marconi conducted microwave tests from two elevated terminals —one at Rocca di Papa and the other at Capo Figari (Sardinia) at a height of 340 m—separated by a distance of 270 km, with an optical range over sea of 150 km.

In these tests it was established by beam swinging that the angle of arrival of the signal was tangential to the horizon and in the direction of the transmitter. Furthermore, for the duration of the tests, the signals were always present, albeit with notable fading.

Marconi was now well aware of the effects of meteorological conditions upon radiocommunication as is shown by Vanni.[7] He was of the opinion that the reception of radio waves at distances beyond the horizon could be attributed to the effects of the lower atmosphere. He was also convinced that some stratification would eventually be identified which would enable microwaves to be usefully propagated to distances of the order of 400–500 km. With this in mind the supporting structures of both transmitting and receiving parabolic aerials were modified in a manner to allow the main aerial lobes to be elevated by substantial amounts. With this facility tests were carried out in the autumn of 1932 between Rocca di Papa and the *Elettra* anchored in the harbour at Venice, a distance of 400 km. The optical range in these particular experiments, because of intervening hills, was restricted to 70 km. Reception tests were made while the transmitting and receiving parabolic aerials were synchronously tilted upwards by successive small angles of elevation. Fig. 4 shows the transmitting aerial arranged for a substantial vertical angle.

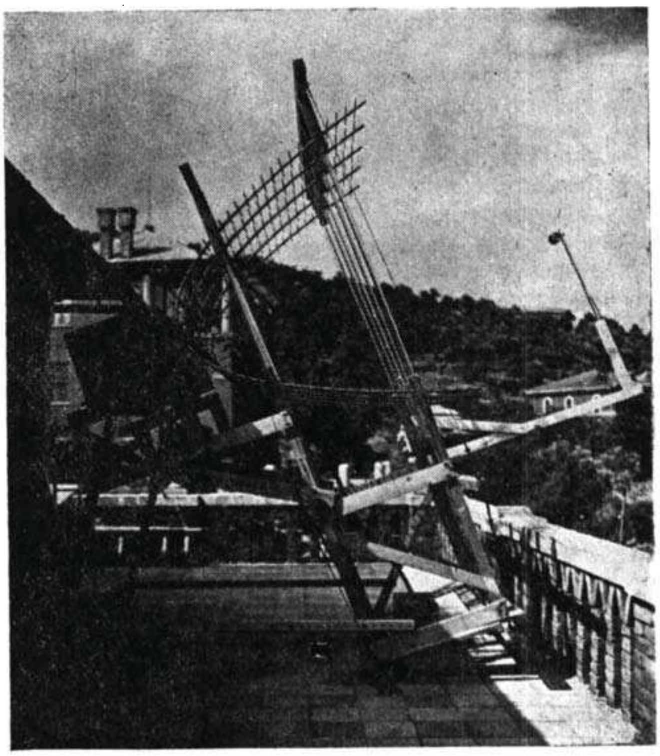


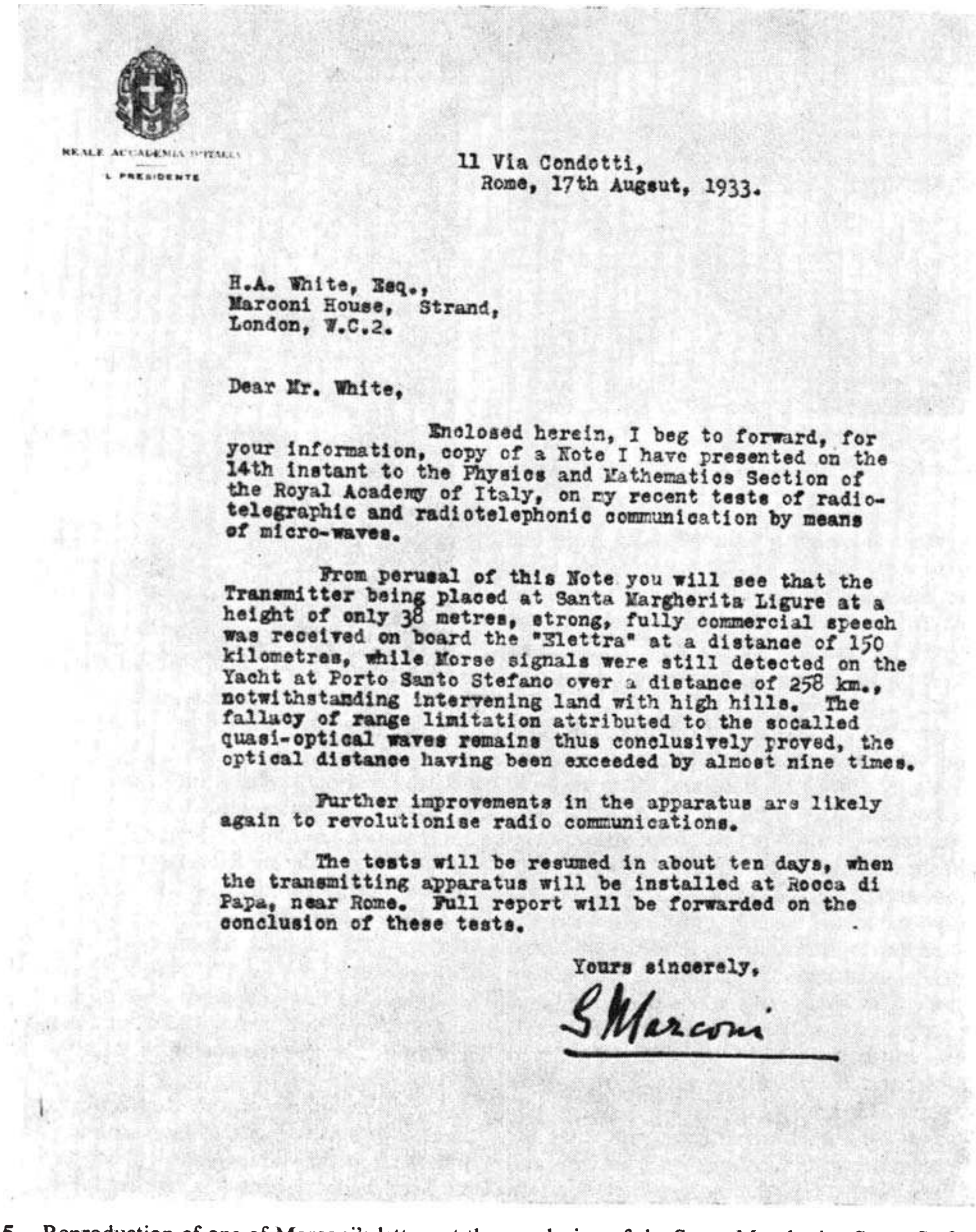
Fig. 4.—The five-unit fishbone parabolic aerial tilted at a substantial vertical angle during the Rocca di Papa–Venice long-distance test.

The experiment failed—probably because the distance was too ambitious considering the relatively low power radiated. On the other hand the author, who was responsible for the instrumentation of the test, has never been able to satisfy his conscience that the receiver and transmitter were ever brought into tune with one another. It was, in fact, the first time that an attempt was made to receive signals over a great distance without first being able to commence the experiment in the vicinity of the transmitter, where the tuning procedure was relatively easy and certain.

After the failure of the Rocca di Papa–Venice experiments great efforts were made to increase the power of the transmitter and the general stability and efficiency of the apparatus. The resulting improvement was so effective that Marconi decided to carry out further propagation tests with the *Elettra* in August, 1933.

The new transmitter was installed again at Santa Margherita. The *Elettra*, with the receiving aerial installed at the stern, then steamed in a south-easterly direction along the Italian coast. Signals were monitored continuously during the voyage, and, apart from the occasions when navigational requirements made it impossible to maintain the receiving parabolic aerial directed towards the transmitter, signals were received throughout the voyage as far as the harbour of Santo Stefano. The total distance covered was 258 km, i.e. nine times the optical distance. This distance was achieved in spite of the fact that high hills intervened at two points along the route.

Carroll[8] has recently pointed out that this particular experiment indicated, without doubt, that Marconi had discovered experimentally the existence of microwave propagation beyond the horizon which could not be explained by diffraction and refraction. This was the identical point of view expressed by Marconi[9] himself in the account he gave of the experiment to the Physics and Mathematical Section of the Royal Academy of Italy on the 14th August, 1933.


REALE ACCADEMIA D'ITALIA
IL PRESIDENTE

11 Via Condotti,
Rome, 17th August, 1933.

H.A. White, Esq.,
Marconi House, Strand,
London, W.C.2.

Dear Mr. White,

Enclosed herein, I beg to forward, for your information, copy of a Note I have presented on the 14th instant to the Physics and Mathematics Section of the Royal Academy of Italy, on my recent tests of radio-telegraphic and radiotelephonic communication by means of micro-waves.

From perusal of this Note you will see that the Transmitter being placed at Santa Margherita Ligure at a height of only 38 metres, strong, fully commercial speech was received on board the "Elettra" at a distance of 150 kilometres, while Morse signals were still detected on the Yacht at Porto Santo Stefano over a distance of 258 km., notwithstanding intervening land with high hills. The fallacy of range limitation attributed to the socalled quasi-optical waves remains thus conclusively proved, the optical distance having been exceeded by almost nine times.

Further improvements in the apparatus are likely again to revolutionise radio communications.

The tests will be resumed in about ten days, when the transmitting apparatus will be installed at Rocca di Papa, near Rome. Full report will be forwarded on the conclusion of these tests.

Yours sincerely,

G Marconi

Fig. 5.—Reproduction of one of Marconi's letters at the conclusion of the Santa Margherita–Santo Stefano tests.

tests would undoubtedly have continued and our present knowledge of tropospheric mechanisms might well have been much more advanced.

Considered in retrospect there is surely every reason to believe that, by his repeated demonstrations that signals were receivable beyond the horizon, even up to eight or nine times the optical range on both 30 and 600 Mc/s, Marconi utilized the same tropospheric mechanisms which we ourselves are only now actively investigating. It is interesting to note furthermore that we are slowly coming to the same conclusions that Marconi reached in one of his letters, reproduced in Fig. 5, written a quarter of a century ago.

Sir Ambrose Fleming[10] has emphasized that Marconi's predominant interest was not in purely scientific knowledge *per se*, but in its practical application for useful purposes. So it was typical of Marconi that, having proved to his own satisfaction that microwaves could be utilized for all manner of purposes, he set about developing and demonstrating some of the practical applications. Amongst these applications were specific navigational aids,[11] which imposed a heavy demand upon the services of the *Elettra*, and precluded her further participation in propagation experiments. Had it not been for this, the propagation tests would undoubtedly have continued (see above).

ACKNOWLEDGMENT

The author wishes to thank the Engineer-in-Chief of Marconi's Wireless Telegraph Co., Ltd., for permission to publish the paper.

REFERENCES

(1) Marconi, G.: 'Phenomena Accompanying Radio Transmission', *Marconi Review*, 1931, No. 32, p. 1.

(2) Uda, S., Seki, T., Hatakeyama, K., and Sato, J.: 'Duplex Radio Telephony with Ultra Short Waves', *Journal of the Institute of Electrical Engineers of Japan*, 1931, **51**, p. 449.

(3) Pistor, W.: 'Reception of Ultra-Short Electric Waves', *Zeitschrift für Hochfrequenztechnik*, 1930, **35**, p. 135.

(4) Clavier, A. G., and Gallant, L. C.: 'Anglo-French Micro-Ray Link between Lympne and St. Inglevert', *Electrical Communication*, 1934, **12**, p. 222.

(5) 'First Micro-wave Radio Telephone Service', *Marconi Review*, 1933, No. 40, p. 29.

(6) Marconi, G.: 'Radio Communication by Means of Very Short Electric Waves', *Proceedings of the Royal Institution*, 1933, **27**, p. 509.

(7) Vanni, G.: 'Marconi's Recent Short-wave Tests', *Pontificia Accademia delle Scienze*, 1930, **83**, p. 216.

(8) Carroll, T. G.: 'Marconi's Last Paper "On the Propagation of Micro-waves over Considerable Distances",' *Proceedings of the Institute of Radio Engineers*, 1956, **44**, p. 1056.

(9) Marconi, G. (Translation by Fano, R. M.): 'On the Propagation of Micro-waves over Considerable Distances', *Proceedings of the Institute of Radio Engineers*, 1956, **44**, p. 1057.

(10) Fleming, A.: 'Guglielmo Marconi and The Development of Radio Communication', *Journal of the Royal Society of Arts*, 1937, **86**, p. 41.

(11) Shankland, E. C.: 'Marconi's Wireless Pilot', *Nature*, 1934, **134**, p. 387.